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MEASUREMENT OF $t\bar{t}$ PRODUCTION CROSS SECTION AT THE TEVATRON

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Abstract

We report on the measurement of the $t\bar{t}$ production cross section obtained by CDF and DØ experiments with $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The analyses presented here refer to $\int \mathcal{L}dt \approx$ 110 pb^{-1} collected at the Fermilab Tevatron collider during the run 1992-96. About 85% of the possible $t\bar{t}$ decays have been studied in different channels classified according to the number of high$-p_T$ leptons found in the final state. The production cross section has been measured in each individual channel and then combined into a single value for each experiment, which is $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb for CDF and $\sigma_{t\bar{t}} = 5.77 \pm 1.76$ pb for DØ.

1 Introduction

The discovery of the fifth quark, b, in the Υ in 1977, initiated the search for the top quark which completes the three quark families. The sequence of null results, both at electron and hadron colliders, lead to increasing values on the top mass limit. In 1994 CDF presented the first evidence [1] of top production in pairs with a cross section of about 14 pb. The mass of this quark was measured to be about 174 GeV/c^2. The discovery was announced one year later both by CDF and DØ [2], [3]. They measured a cross section of $6.8^{+3.6}_{-2.4}$ and 6.4 ± 2.2 pb with a mass of $176 \pm 8(stat) \pm 10(syst)$ and $199^{+19}_{-21}(stat) \pm 22(syst)$ GeV/c^2, respectively.

2 $t\bar{t}$ production and decay

In the Standard Model, at the energies of the Tevatron ($\sqrt{s}$ = 1.8 TeV), top quarks are predominantly produced in pairs, mainly through $q\bar{q}$ annihilation (due to the high value of the top mass). The Next–to–Leading–Order theoretical calculations provide a production cross section of 4.75–5.5 pb for a top mass of 175 GeV/c^2 [4], [5], [6].

Both CDF and DØ collected about 110 pb^{-1} of integrated luminosity between 1992 and 1996. This means that about 500 $t\bar{t}$ pairs have been produced in each detector. Such a number is very small when compared with those expected from inelastic scattering and W boson production. For instance W production has a rate about 3 orders of magnitude larger. Within the Standard Model each top quark is expected to decay almost 100% of the times into a Wb pair so the final state is expected to be $W^+bW^-\bar{b}$. Such a final state is classified according to the W decay, counting how many $W's$ decay into a quark pair or into a lepton pair. So we have the following categories with their branching ratios:

Categories	BR	%
Dilepton: $e\mu, ee, \mu\mu + jets$	$\frac{4}{81}$	5%
Single lepton: e or μ + jets	$\frac{24}{81}$	30%
All hadronic: only jets	$\frac{36}{81}$	44%
τ*–Dilepton:* $\tau e, \tau\mu + jets$	$\frac{4}{81}$	5%
Others: $\tau\tau$, $\tau + jets$	$\frac{13}{81}$	16%

3 Event selection

The event selection is based on the signature specific for each individual channel and is based essentially on lepton and jet counting. Kinematic and topological requirements are added in order to reduce the backgrounds.

3.1 Lepton identification and jet reconstruction

Essential for the event selection is lepton identification. Both electron and muon ID are based on the isolation of the track with respect to the surrounding activity and on the matching of these tracks with the showers in the calorimeters or the stubs in the muon chambers. Electrons are also compared in their shower development with test beam data, while muons must have a characteristic energy deposit in the calorimeter.

Jets are defined as clusters of contiguous calorimeter towers and are reconstructed using a cone of fixed radius in $\eta - \phi$ space. The radius of this cone is 0.4 for CDF and 0.5 for DØ.

3.2 Dilepton event selection

Dilepton events are characterized by the presence of 2 isolated high–p_T leptons (either e or μ), a large missing transverse energy $\not\!\!E_T$ to account for the two undetected neutrinos and 2 or more jets, two of which are expected from the 2 b's. In this channel the dominant backgrounds are WW production, $Z \rightarrow \tau\tau$, events with misidentified leptons and Drell–Yan events. This channel has a good Signal–to–Background ratio, S/B, but unfortunately the yield is small.

3.3 Lepton + jets event selection

Lepton + jets events are characterized by the presence of one isolated high–p_T lepton (either e or μ), large $\not\!\!E_T$ to account for the undetected neutrino and 4 or more jets, two expected from the 2 b's and two expected from a W. The dominant backgrounds come from $W + jets$ production and from QCD multijet events where one jet is misidentified as a lepton. In this channel the backgrounds dominate and we can reduce them by applying a b–jet tagging, either looking for displaced vertices (i.e. SVX tagging for CDF) or for low–p_T leptons from the b semileptonic decays (i.e. SLT for CDF or μ–tag for DØ). Another approach involves the application of specific kinematic and topological requirements. DØ does this by using three variables: aplanarity, sum of jet transverse energy and the transverse W energy.

3.4 All hadronic event selection

All hadronic events contain 6 jets (two from the b's and two from each W). In addition these events have a large total transverse energy, $\sum E_T$. The dominant background comes from QCD multijet production and is huge ($S/B \approx 1/500$), so we need to apply stringent kinematic and topological requirements and single (SVX) or double (SVX^2) b–tagging.

3.5 Other channels

CDF considers also events with an electron or muon plus a τ which decays hadronically into 1 or 3 prongs. These events have a large $\not\!\!E_T$, 2 or more jets and large $\sum E_T$. The backgrounds to this channel come from $Z \rightarrow \tau\tau$ events, WW and WZ production and from leptonic events with jets misidentified as τ's. This is a complementary channel since it features low S/B and small yield.

DØ considers also $e\nu$ events in order to extend the restricted phase space of the ordinary dilepton events and also to consider τ decay channels. The signature of this channel has one isolated high–p_T electron, large $\not\!\!E_T$, 2 or more jets and a large $e\nu$ transverse mass. In this case the dominant backgrounds come from $W + jets$ production and events with jets misidentified as electrons.

3.6 Summary of the selection requirements

The variables used for the event selection are essentially jet/lepton multiplicity ($N(jet)$, $N(\ell)$) and the corresponding $p_T/E_T/\eta$ thresholds, missing transverse energy ($\not\!\!E_T$), total transverse energy of jets alone ($\sum E_T$) or including leptons (H_T), aplanarity (A), dilepton invariant mass ($M_{\ell\ell}$), W transverse energy (E_T^W) and the presence of b–tags. The value chosen for these cuts are summarized in Tables 1 and 2.

Table 1: Summary of CDF cuts

CDF Cut	$\ell\ell$	$\ell + jets$	all had
$\not{E}_T >$	25 *	20	–
$N(jet) \geq$	2	3	5
$E_T^{jet} \geq$	10	15	15
$\lvert\eta\rvert_{jet} \leq$	2.0	2.0	2.0
$N(\ell) \geq$	2	1	0
$N(\ell)^{iso} \geq$	1	1	0
$p_T^{\ell} \geq$	20	20	–
$\lvert\eta\rvert_{\ell} \leq$	≈ 1.05	≈ 1.05	–
$\lvert M_{\ell\ell} - M_Z\rvert \geq$	15	–	–
b–tag	–	SVX/SLT	SVX/SVX^2
$\sum E_T^{jets} \geq$	–	–	300/300
$\sum E_T^{jets}/\sqrt{\hat{s}} \geq$	–	–	0.75/0
$A + 0.0025 \sum E_T^{j\geq 3} \geq$	–	–	0.54/0
$\ell = e$ or μ	$*$=50 if $\Delta\phi(\not{E}_T, \ell\ or\ nearest\ jet) < 20^0$		
Energies (momenta) are measured in GeV (GeV/c)			

4 Summary of individual results

CDF sees 10 dilepton events over a background of 2.1 ± 0.4 events. One of the 10 events has been recognized as a $\mu\mu\gamma$ event. DØ isolates 5 dilepton events over a background of 1.4 ± 0.4.

In the lepton + jets channel, CDF selects 34 events with a displaced vertex and 40 with a soft lepton. The expected backgrounds are 8.0 ± 1.4 and 24.3 ± 3.5 events respectively. DØ observes a total of 30 events with a background of 11.0 ± 2.0 events.

CDF has results also in the all hadronic channel with two methods (single and double b–tagging) selecting 187 and 157 events over a background of 141.9 ± 12.2 and 119.5 ± 17.9 events respectively.

In the $e\nu$ channel DØ sees 4 events with a background of 1.16 ± 0.34.

5 Cross section measurement

The production cross section is evaluated considering the number of candidates, N_{obs}, the expected background, N_{bkgd}, the total efficiency, ϵ_{tot}, and the integrated luminosity, $\int \mathcal{L}dt$ according to the formula

$$\sigma = \frac{N_{obs} - N_{bkgd}}{\epsilon_{tot} \cdot \int \mathcal{L}dt}$$

The measurements are made in each channel separately and then combined into a single value for each experiment.

For the time being CDF combines only the channels with two leptons or with one lepton plus b–tag. The combined cross section amounts to $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb. This value refers to a top mass of 175 GeV/c^2 and changes by $\approx \pm 5\%$ for a mass lower/higher by 15 GeV/c^2. The all hadronic value agrees within the uncertainties and will be included soon in the combination.

DØ combines all the leptonic channels into a single measurement of $\sigma_{t\bar{t}} = 5.77 \pm 1.76$ pb assuming a top mass of 170 GeV/c^2. In this case the cross section changes by $\approx 15\%$ if the

Table 2: Summary of DØ cuts

DØ Cut	$e\mu$	ee	$\mu\mu$	$e/\mu + jets$	$e/\mu + jets/\mu$
$\not{E}_T >$	20	25 *	*	25/20	20 *
$N(jet) \geq$	2	2	2	4	3
$E_T^{jet} \geq$	20	20	20	15	20
$\|\eta\|_{jet} \leq$	2.5	2.5	2.5	2.0	2.0
$N(\ell)^{iso} \geq$	2	2	2	1	1
$p_T^{\ell} \geq$	15	20	15	20	20
$\|\eta\|_{\ell} \leq$	2.5/1.7	2.5	1.7	2.0/1.7	2.0/1.7
A (jets+W)	–	–	–	0.065	0.04
$H_T \geq$	120	120	100	180	110
$E_T^W \geq$	–	–	–	60	–
$N(\mu - tag) \geq$	–	–	–	–	1
$p_T^{\mu-tag} >$	–	–	–	–	4
$\Delta R_{jet,\mu} <$	–	–	–	–	0.5
$\ell = e$ or μ	$*$: extra cuts to reject Z's, cosmics and bad μ's				
Energies (momenta) are measured in GeV (GeV/c)					

mass differs by 10 GeV/c^2.

The individual and combined measurement are shown in Figure 1 along with the theoretical expectation.

6 Single top production

Top quarks can be produced singly through Wg fusion or virtual W. The production cross section [7] is expected to be about two times smaller than the $t\bar{t}$ pairs one while the acceptance is reduced by a factor of 5. We thus expect only about 2 or 3 events which have not been observed yet.

7 Conclusions

We reported the results obtained in 110 pb^{-1} of data collected at the Tevatron with the CDF and DØ detectors. After the top quark discovery, the focus of both experiments in on determining the cross section as accurately as possible through an optimized event selection and the study of as many different channels as possible.

The production cross section measured by CDF amounts to $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb (for a top mass of 175 GeV/c^2), while DØ measures $\sigma_{t\bar{t}} = 5.77 \pm 1.76$ pb (for a top mass of 170 GeV/c^2). Both values are obtained using only channels with at least one lepton. CDF will include soon also the all hadronic measurement.

Within the quoted uncertainties these values agrees with NLO theoretical calculations, the CDF value being about 1σ higher.

The total uncertainty on the cross section amount to about $25 - 30\%$. Considering the integrated luminosity of ≈ 2 fb^{-1} foreseen for Run II by the year 2001, we expect to reduce the uncertainty to less than 10% for each experiment [8].

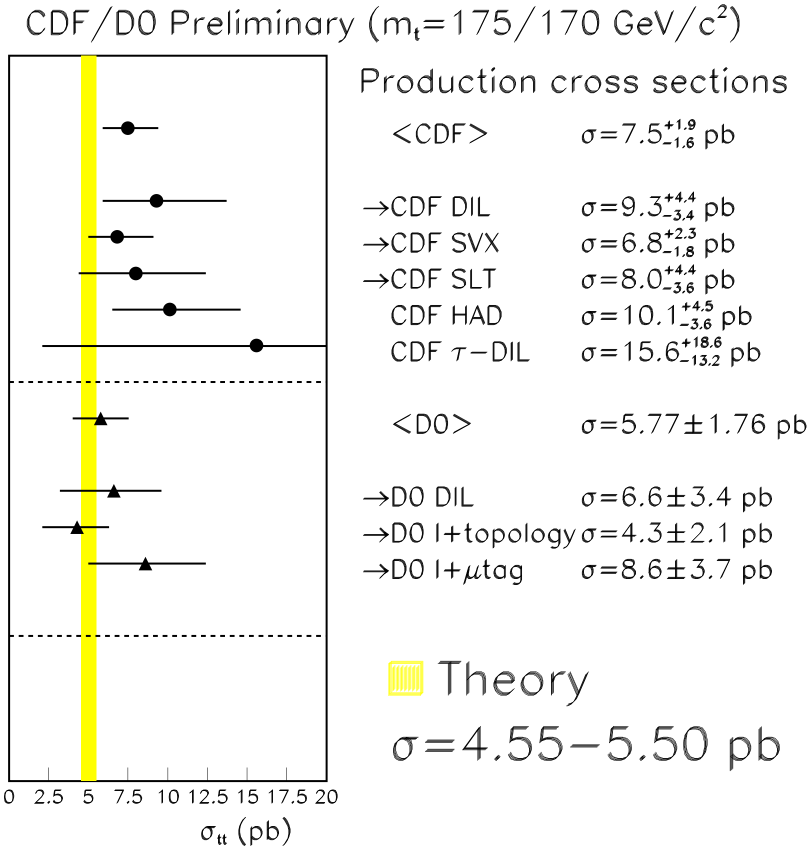

Figure 1: $t\bar{t}$ production cross section for individual channels. The arrows indicate the channels which are combined in the average for each experiment. The vertical band represents the spread in the theoretical expectations.

References

[1] F. Abe *et al.*, Phys. Rev. **D50**, 2966 (1994)

[2] F. Abe *et al.*, Phys. Rev. Lett. **74**, 2626 (1995)

[3] S. Abachi *et al.*, Phys. Rev. Lett. **74**, 2632 (1995)

[4] E. Laenen *et al.*, Phys. Lett. **B321**, 254 (1994)

[5] E. Berger and H. Contopanagos, Phys. Rev. **D54**, 3085 (1996)

[6] S. Catani *et al.*, Phys. Lett. **B378**, 329 (1996)

[7] T. Stelzer and S. Willenbrock, Phys. Lett. **B357**, 125 (1995)

[8] D. Amidei *et al.*, FERMILAB-Pub-96/082